NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC APOLLO 13 INVESTIGATION TEAM

FINAL REPORT

PANEL 9:

G+D only

SAFETY, RELIABILITY AND QUALITY ASSURANCE

MAY 1970

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

FINAL REPORT

PANEL 9

SAFETY, RELIABILITY AND QUALITY ASSURANCE

M. L. RAINES
CHAIRMAN, PANEL 9
MSC APOLLO 13 INVESTIGATION TEAM

SUPPORT TO PANEL 1

John C. French
Jack A. Jones
Bill J. McCarty
James E. Eaton
Jack H. Cohen

SUPPORT TO PANEL 5

L. T. Spence
Charles N. Rice
Edison M. Fields
Norbert B. Vaughn
C. E. McCollough, Jr.

SUPPORT TO PANEL 6

John C. French
Joseph H. Levine

SUPPORT TO PANEL 7

Quintin T. Ussery

SUPPORT TO PANEL 8

John W. Conlon

SUPPORT TO PANEL 11

William L. Baldwin

FINAL REPORT

PANEL 9

SAFETY/RELIABILITY AND QUALITY ASSURANCE

I. INTRODUCTION

a. Scope

The Safety/R&QA Panel 9 to the MSC Apollo 13 Investigation Team was established to provide the following functions:

1. Act in an advisory capacity to the Team Manager

2. Provide specific documentation and documentation control

3. Provide technical support to Panels 1, 5, 6, 7, 8, 11 and members of the Investigation Board

This report summarizes these activities and presents Safety/R&QA (Panel 9) recommendations.

b. Organization

The Safety/R&QA support through Panel 9 and through Panels 1, 5, 6, 7, 8, and 11 is shown on the preceding page. Names of key people supporting these panels are listed. These people were supported by personnel from NASA Safety/R&QA elements, from their Boeing Company and General Electric Company support contractors, and by appropriate hardware contractor personnel.

The Safety/R&QA summary panel reports referenced in Section VI provide additional details of the support supplied. It is estimated that at the peak of the activity, the Safety/R&QA Offices had more than 200 personnel directly supporting the investigation.

In addition to the technical support referenced above, approximately two thousand documents were retrieved, reproduced or otherwise made available to the panels and to members of the Investigation Board. Most of the documents are listed in the individual panel summary reports referenced in Section VI of this report. Others supplied to members of the Investigation Board are listed in Enclosure A. Still others supplied to team panels and not otherwise referenced are listed in Enclosure B of this report.

c. Activities Prior to Formation of the Apollo 13 Investigation Team

During the Apollo 13 mission, the planned Safety/R&QA support was set up to review flight anomalies as they occurred and to provide related data, information, and recommendations through the Safety/R&QA representatives on the Mission Monitoring Team. At the time of the cryogenic tank incident, the Safety/R&QA organization furnished supporting data and information related to the incident and reviewed changes in flight plan and flight procedures as they related to hardware capabilities to assure "safe recovery". Data, information, and recommendations from these activities were furnished in real-time to the Mission Monitoring Team. Immediately after splashdown an effort was initiated to collect data on certification and problem history and KSC checkout activities on problem related hardware. In addition, timelines and other basic information were studied in preparation for the formal team activities. Safety/R&QA support continued as the Apollo 13 Investigation Team was being organized. The remainder of this report describes the support furnished to the Investigation Team.

II. GENERAL ACTIVITIES BY SAFETY/R&QA

Panel 9 supported the investigation in the following areas:

- Served as overall Safety/R&QA advisor to the team
- Provided support to board members
- Provided support to Panels 1, 5, 6, 7, 8, and 11 as follows:

PANEL 1, Spacecraft Incident Investigation

- Compared previous safety related flight and test anomalies with Apollo 13 flight data
- Reviewed previous safety assessments of Apollo 7 through 13
- Evaluated test results and test analyses
- Provided Data Centers to enable:
  - Control of pertinent historical documents, records, and data
  - Security of data
- Reliability/Quality Records/Evaluation
  - Prepared history and reevaluated certification test data for cryogenic O_2 tank

- Prepared synopsis of test procedures used at Beech Aircraft Corporation on the cryogenic O_2 tank number 2 and all associated equipment

- Provided failure history of electrical connectors used on the cryogenic O_2 tank

PANEL 5, Corrective Action Study and Implementation

- Analyzed safety impact of recommendations

- Evaluated alternatives relative to previous safety assessments

- Evaluated test requirements and results

- Assisted in establishing qualification requirements for possible cryogenic O_2 tank redesign

- Evaluated alternative designs

PANEL 6, Related Systems Evaluation

- Analyzed proposed revisions for reliability and safety considerations

- Evaluated alternatives relative to previous safety assessments

- Assessed nonmetallic material compatibility of all oxygen, fuel, and oxidizer tank assemblies and line components with the exception of cryogenic oxygen tanks

- Provided information on contamination requirements

- Reviewed and assessed certification and failure history, failure mode and effects analysis and single point failure summaries and limited life requirements

- Provided R&QA inputs to Systems Engineering team members

- Provided inputs on emergency backup modes

- Provided information on pressure vessel explosion protection

- Provided information on pyro initiator debris

- Provided circuit breaker data

- Reviewed and provided inputs into final report

- Determined energy levels of the effect of faulted electrical components oxygen and oxidizer interfaces with the exception of the cryogenic O_2 tank

PANEL 7, Reaction Processes in High Pressure Fluid Systems

- Furnished documentation relative to LOX compatibility of materials
- Listed and reevaluated two waivers against Apollo 13 on O_2 fluid cleanliness

PANEL 8, High Pressure Oxygen Systems Survey

- Gathered and reviewed information on fires and/or explosions in O_2 enriched environments of greater than ambient pressures
- Assembled applicable design standards and safety criteria
- Furnished procedures used at MSC for cleaning of facility O_2 equipment

PANEL 11, Administration, Communications, and Procurement

- No significant activity

III. FINDINGS

1. The existing system for control of the hardware certification test programs and assessment of completion is adequate.

2. Formal closeout and recurrence control of reported hardware problems is adequate.

3. The current MSC method for R&QA and Engineering review of hardware nonconformances and material review board actions is adequate.

4. Adequate background information on both specific and related generic hardware is contained in the record system.

5. There is a comprehensive spacecraft cabin materials control program. The area of materials compatibility in high pressure fluids is not completely understood.

IV. RECOMMENDATIONS

1. It is recommended that the present management system involving decisions at all levels on flight hardware be reviewed. The objective would be to optimize visibility to management concerning background on the specific and related generic hardware during the decision-making process.

2. It is recommended that a comprehensive testing program to establish materials compatibility with high pressure oxygen and other fluid systems as used in spacecraft systems be undertaken by MSC.

V. SUMMARY

The Safety/R&QA Offices concur with the findings and corrective action defined to date relative to the Apollo 13 cryogenic tank failure, although certification and acceptance test requirements of the new tanks have not yet been completely defined.

Disposition of the recommendations submitted by Safety/R&QA representatives through their assigned panels has been satisfactory.

M. L. Raines
Chairman, Panel 9
MSC Apollo 13 Investigation Team

VI. REFERENCES

The following is a list of Summary Reports submitted by Safety/R&QA support to the Apollo 13 Investigation Team Panels:

Reference 1: Final Report, Panel 1, Group b, Historical Records Handling and Cataloging, ND/May 18, 1970.

Reference 2: Panel 5a, CSM, Corrective Action Study and Implementation Panel, Safety and R&QA Report to Panel 9, SN/May 15, 1970.

Reference 3: Panel 5b, Lunar Module, Corrective Action Study and Implementation Panel, R&QA and Safety Report to Panel 9, NA/May 18, 1970.

Reference 4: Panel 5c, Government-Furnished Equipment, Corrective Action Study and Implementation Panel, Safety and R&QA Report to Panel 9, SN/May 15, 1970.

Reference 5: Input to Panel 9, Safety and R&QA Summary of R&QA Participation to Panel 6, Related Systems Evaluation, NB/70-M525, May 14, 1970, and NB/70-M548, May 20, 1970.

Reference 6: Panel 7, Reaction Processes in Flight Pressure Fluid Systems, ND/May 18, 1970.

Reference 7: Panel 8, High Pressure Oxygen Systems Panel, Safety and R&QA Report to Panel 9, SM/May 14, 1970.

ENCLOSURE A

Panel 9 - Safety and R&QA Documents Transmitted to the Apollo 13 Investigation Board (Messrs. Whitten and Ginter)

Documents listed below were transmitted to:

a. Mr. D. Ginter

Problem Control System Briefing Charts
CSM Open Problem List - dated April 23, 1970
CSM-108 Launch Readiness Report, issues 8 and 11
24-Hour Notification Report
Anomaly List - Apollo 12
Apollo 13 RFF (Friday night report)
R&QA O_2 Tank Certification Report

b. Mr. J. Whitten

Functions and Organization Safety Office - MSCI 1138.1B and Applicable Position Descriptions
Power and Propulsion Division (Fuel Cells/Cryogenics) Applicable Position Descriptions
MSC Safety Plan - MSCM 1701 (currently being revised)
Boeing Apollo TIE System Safety Plan - D2-118036-1A
Organization Boeing System Safety
Boeing System Safety Technical Management Review (typical)
Functions and Organization ASPO - MSCI 1141.1
Assistant Program Manager Flight Safety, ASPO, MSCA 67-126 and Applicable Position Descriptions
Requirements for Apollo Contractor Safety Plan (2-17-69)
KSC-MSC Relationships at the Cape
Apollo 13 Safety Support - Safety Office and Boeing System Safety
Boeing - Selected Areas of Concern for Apollo 6 (Fuel Cells and Cryogenics) D2-118072-1
Boeing - Apollo Spacecraft System Safety Assessments - Apollo 11 and 13 - 2 volumes each
Boeing - Apollo Spacecraft System Safety Assessment - Apollo 7 to 13 Excerpts pertaining to CSM Cryogenic Oxygen System
Detanking Cryo Oxygen Problem at KSC - DR-0512
Nonmetallic Materials in the Oxygen Storage Tank Assembly
Configuration Control Board Minutes regarding CSM Cryogenics
MSC R&QA/Safety Suspect Flight Anomaly Report - Apollo 13
Historical Summary of the Apollo 13 Cryo Oxygen Tank No. 2 (S/N 10024XTA0008)
MSC Safety Office Activities prior to and during the Apollo 13 Incident through Splashdown, May 22, 1970
Apollo 13 Pre-Launch R&QA Activities

R&QA (GE) Data Bank - Flight Anomalies
Development Certification Test History of Cryo Tank No. 2
Apollo FMEA (Cryo System); Single Point Failure Summary
Skylab FMEA (Cryo System)
Apollo 204 Accident - Cryo Oxygen regarding Action Items (NASA)
Apollo 204 Accident - Cryo Oxygen regarding Design Changes
North American Rockwell Contract NAS9-150, System Safety Monthly Report, Period ending February 28, 1970
System Safety Audit Report on North American Rockwell, Space Division, Downey, California, dated October 1, 1969
North American Rockwell, Space Division, Safety Organization
Fault Tree Analysis, Apollo 13 Incident, dated May 12, 1970
Letter to NASA Hqs., from M. L. Raines, dated April 29, 1970, Subject, R. Emerson Harris (Aerospace Safety Advisory Panel Report) "System Safety Review and Evaluation of the MSC and Its Principle Apollo Prime Contractors, period - October 7-16, 1968"
Manpower Summary R&QA/Safety as of April 30, 1970
Mission Log Book - Apollo 13
Apollo Mission-Safety Concerns Status (Boeing) March 11, 1970
FRR Flight Safety Assessment, Apollo 13 Mission, dated February 26, 1970
Apollo 13 Spacecraft Readiness Status, dated March 6, 1970
MSC Comments dated July 7, 1969, on Combined Aviation, Systems, and Industrial Safety Survey, MSC, April 14-17, 1969
R&QA Assessment Statement Apollo 13 Flight Readiness Review
R&QA Weekly Activity Reports to AA/R. R. Gilruth for periods for January 1, 1970 to May 16, 1970 inclusive
R&QA Weekly Activity Reports to PA/Col. McDivitt for periods January 1, 1970 to May 16, 1970 inclusive
R&QA Monthly Assessment Reports for October and November 1969
Phase II LM-7 CARR - Trip Report, April 16-17, 1969
CSM-109 FRR at KSC - Trip Report, January 16-17, 1970
Mode IV Abort Report (Boeing), November 1969
CSM-109 Phase III CARR, Downey, June 3-4, 1969, Trip Report
Apollo 13 R&QA Flight Readiness Assessment

Documents Distributed to Board Members May 21, 1970

Apollo Spacecraft Nonmetallic Materials Requirements, MSC-PA-D-67-13, February 9, 1968, (Addendum No. 1, November 7, 1969)
Procedures and Requirements for the Flammability and Offgassing Evaluation of Manned Spacecraft Nonmetallic Materials, D-NA-0002, July 1968
Nonmetallic Materials Design Guidelines and Test Data Handbook, MSC-NA-D-68-1, Revision F, November 26, 1969

ENCLOSURE B

The following reports were supplied to Apollo 13 Investigation Team members:

1. "Apollo 13 Investigation, Panel 6 - Related Systems Evaluation Inputs from Reliability and Quality, Revision 1," NB/70-M,+0, dated May 15, 1970.

2. "A Literature Survey of Reports of Unexpected Incidents in the Presence of Oxygen at Concentrations and Pressures Higher than that of the Normal Atmosphere," dated May 14, 1970, provided to Panel 8.

3. "Spacecraft 109 - Shelf Incident Report," dated May 12, 1970, (copy attached).

Item 3, Enclosure B

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC APOLLO 13 INVESTIGATION TEAM

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

REPLY TO
ATTN OF ND15/M70-18

MEMORANDUM TO : Leader, Apollo 13 Investigation Team

FROM : Panel 9 Chairman

SUBJECT : Spacecraft 109 - Shelf incident report

The purpose of this report is to provide a chronological history of events leading to and including this incident at the contractor's plant, Downey, California.

On August 22, 1968, North American Rockwell (NR) Engineering Order (EO) M702138, was released, which required a change to vac-ion pumps to prevent corona discharge. The shelf on CSM 106 was selected to be removed and updated for CSM 109. This was a normal inline update. EO 702134-1 and 2 authorized the rework and test of the O^2 tank assembly and vac-ion pumps by Beech Aircraft Corporation.

A manufacturing order (fair ticket) number 488757, was written August 24, 1968, against EO M702138 to provide for removal and rework of the O^2 shelf V37-454200-41 S/C 106.

On October 21, 1968, approximately 10:00 in the morning, service module 106 was returned to test stand, position 2A, Bldg 290, NR Downey. The SM was rotated 90° from its normal installation position to accommodate the overhead crane, the 9EH-1275 (counter balance) and the 9EH-1009 (O^2 shelf removal fixture).

In this position, sector #4 of the SM would be facing the front of the stand. The floors of the stand are designed to fold back and the removal equipment can be easily attached.

At approximately 3:30 p.m. on October 21, 1968, an attempt was made to remove the O^2 shelf from SM 106. The 9EH-1009 shelf adapter model was attached to the O^2 shelf and the 9EH-1275 counter weight sling was attached to the overhead crane. The O^2 shelf was lifted approximately two inches, the counter balance was being adjusted, and the overhead crane was being moved outward when the 9EH-1009 shelf adapter broke at the lower attachment weld. Immediately following the weld break on the 9EH-1009 shelf adapter, the O^2 shelf dropped back to its mating surface in the SM structure. The 9EH-1275 counter-weight sling swung up tting the test stand structure and damaging a light fixture. The area was immediately roped off and industrial security was notified. There were no personal injuries.

Disposition record (DR) A80327, item #158, was initiated at the scene and photographs were taken of the 0^2 shelf, the immediate surrounding area and the broken 9EH-1009 adapter. After further investigation, it was discovered in preparing the 0^2 shelf for removal from the service module, one of the 11 shelf retaining bolts was inadvertently left in place. As part of the corrective action on the disposition record #158, sequential inspections were performed on the shelf and in the surrounding areas. Dye penetrant inspections were made in the areas of the #3 radial beam stiffner and the structure was found acceptable. During the inspection of the surrounding areas, a small identation (ding) was noted directly above oxygen tank number two in the face sheet of the fuel cell shelf. This indentation was written up on disposition report A112436 #159 and later dispositioned as a normal standard repair.

The 9EH-1009 fixture was repaired by adding stiffners to either side of the adapter fixture along with rewelding the tubing and the 0^2 shelf was removed and taken to the systems test laboratory for the vac-ion modification and subsequent testing on October 22, 1968.

A manufacturing order (no number) was issued October 28, 1968, to transport the 0^2 shelf from Bldg 290 to Bldg 288 for further testing.

On November 12, 1968, DR 140539 was written by the NASA Quality organization requesting NASA Systems Engineering evaluation for retest provisions resultant from the 0^2 shelf drop incident. The retest requirements were evaluated and the necessary testing was accomplished during the time the 0^2 shelf was in the test cell.

The 0^2 shelf was returned to Bldg #290 on the 20th of November, 1968. Inspection for identification and damage was performed and the 0^2 shelf was installed in SM 109 on the 22nd of November, 1968.

The corrective action taken by NR is as follows:

1. Industrial Security Report (B04453).
2. Corrective Action Record (U.C.) #A80327.
3. W. H. Gray letter to D. D. Myers, NE/68L-10-1373, dated October 23, 1968, NR response 68MA8067, dated November 4, 1968.
4. HAMP Manual update to correct problem 10/29/70.
5. Review and update of handling equipment.
6. Review and revise existing planning.

Enclosures 1 and 2 of this report are the photographs and documents assembled to describe this event.

Copies have been provided to Structures and Mechanics Division and the Investigation Board to determine the impact of this drop and its relationship, if any, with the Apollo 13 incident.

M. L. Raines

Enclosures 12